Review Article

Ultrasound diagnosis and therapeutic intervention in the spine

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Abstract: Spine pathology afflicts people across the globe and is responsible for a large portion of physician visits and healthcare costs. Imaging such as plain radiographs, CT, MRI, and ultrasound is vital to assess structure, function, and stability of the spine and also provide guidance in therapeutic interventions. Ultrasound utilization in spine conditions is less ubiquitous, but provides benefits in low costs, portability, and dynamic imaging. This study assesses ultrasound efficacy in diagnosis and therapeutic interventions for spine pathology. A systematic review conducted via PubMed, MEDLINE, and Google Scholar identified 3,630 papers with eventual inclusion of 73 papers with an additional 21 papers supplemental papers subsequently added. Findings highlighted ultrasound utilization for different structural elements of the spine such as muscle, bone, disc, ligament, canal, and joints are presented and compared with radiographs, CT, and MRI imaging where relevant. Spinal curvature and mobility are similarly presented. Ultrasound efficacy for guided therapeutics about the spine is presented and assessed against other modalities. Ultrasound is a widely used and efficacious modality to guide injections about the spine. Diagnostic utility is less well studied, but shows promise in assessing fractures, posterior ligamentous stability, and intra-operative hardware placement. The low cost, portability, and dynamic imaging ability make it an attractive modality particularly for developing health systems and resource limited environments such as combat settings and the International Space Station. Further study is recommended before broad adoption in diagnostics.

Keywords: Ultrasound; spine; musculoskeletal; therapeutic; intervention

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Introduction

Spinal pathology affects many people in the United States, as approximately 25% of the adult population suffers from low back pain and an additional 15% experiences neck pain (1,2). This accounts for 2% of all physician visits and amounts to annual healthcare costs of $85.9 billion (1). The human spine is composed of multiple different structural elements with varying attributes of thickness, depth, rigidity, and location, together contributing to spinal function (3). To adequately assess these elements, use of imaging studies for diagnosis and management of spinal pathology continues to grow rapidly (4-8). The four predominant imaging modalities are CT, MRI, plain radiographs, and ultrasound."
CT, MRI, and radiographs offer benefits in terms of resolution, widespread use in practice, and consistency in image acquisition and interpretation (1,9). However, they do not offer several advantages compared to ultrasound such as portability, affordability, rapidity, and ability to easily obtain dynamic images (9). Ultrasound has less variability than MRI and CT in terms of accessibility of the equipment (10,11), and has demonstrated efficacy in imaging the musculature, bones, intervertebral discs, nerve roots, the spinal cord, and spinal curvature and mobility (9,12,13).

In some areas, ultrasound has shown comparable results to gold standard modalities like MRI, suggesting possible utility in field situations where MRI is not available (9). These features make ultrasound suitable for use in situations such as emergency trauma assessment, image guided therapeutic intervention in non-surgical settings, utilization in underserved areas with limited healthcare capital, and in remote or otherwise resource-limited environments such as wilderness field stations, combat settings, and aerospace medicine (9,13-15). Spinal pathology is a key topic in aerospace medicine for conditions including chronic low back pain, intervertebral disc decompression, spinal curvature changes, and neck fatigue, and ultrasound may aid in diagnosis and management of these conditions (16-18). This goal of this review is to investigate the efficacy of ultrasound for diagnostic imaging and therapeutic intervention in spinal pathology.

Methods

A systematic review was conducted on currently available information and published literature of human and animal studies regarding ultrasound imaging of the spine, using recommendations and PRISMA guidelines (19). The search query used was (“cervical” or “thoracic” or “thoracolumbar” or “lumbar”) and (“spine” or “spinal”) and (“ultrasound” or “ultrasonography”). Databases included in the literature search were PubMed and MEDLINE. All titles obtained from these search criteria were reviewed. Studies published in a language other than English without available translation were discarded. Articles regarding the topic of interest that did not address ultrasound as a modality to image the spine were discarded. The remainder were reviewed in their entirety. The references of these manuscripts were also searched to identify additional applicable studies. Google Scholar was used as a secondary resource to locate supplementary papers relevant to the topic of interest.

Results

Using these methods, 3,630 references were identified that met search criteria and addressed the topics of interest. In total, 1,485 of these had the search terms present in the title or abstract. Of these, 170 studies were published in a non-English language without readily available translation and were discarded. An additional 196 studies involving non-human subjects were discarded. Thirteen references were discarded for abstract unavailability. A total of 550 articles greater than 20 years old were discarded. And 548 of the remaining articles were identified to address topics out of the scope, such as fetal ultrasound, cadaveric imaging, etc. and were discarded. The remaining 73 articles were reviewed in their entirety. The references of these manuscripts were also searched to identify additional applicable studies. Literature obtained includes in vivo studies, case studies, technical reports, white papers, device operating manuals, and review articles (Figure 1).

Twenty-one supplementary papers relevant to the topic from Google Scholar were added to the set and included in review.

The following subsections discuss ultrasound efficacy in diagnosis and therapeutic intervention for the different elements of the spine.

Efficacy of imaging in diagnosis

Musculature

Muscular anatomy imaging via ultrasound was studied in six of the reviewed articles. Muscular visualization is clinically relevant for activity related neck stress, spinal pathology compensation, and chronic neck pain (17,20,21). Leung et al. (22) showed that the posterior neck muscles and their internal architecture in the cervical spine are easily and effectively imaged. Clear pictures can be gathered of these structures using common modern ultrasound equipment (22). Specific attributes of the musculature such as cross-sectional area, thickness, width, and muscle depth can be visualized in the posterior paraspinal musculature (rectus capitis posterior major, oblique capitis superior, semispinalis capitis, multifidus, erector spinae, and splenius capitis) at rest and during contraction; these measurements were found to be reliable when confirmed against other imaging modalities (21,23-27). Lee et al. compared ultrasound measurements of muscle thickness at rest to corresponding MRI measurements and found similar measurement reliability and better visibility with ultrasound (at C4, C5, and C6
levels: ultrasound =0.67±0.14, 0.70±0.20 and 0.73±0.09 cm, respectively; MRI =0.70±0.12, 0.67±0.15 and 0.70±0.06 cm, respectively) (28). The skin overlying the posterior musculature can also reliably be assessed for thickness (29).

Spinal curvature
Anterior-posterior and lateral curvature measurement of the spine has significant clinical implications for many physicians, including orthopedic surgeons, neurologists, neurosurgeons, and emergency medicine physicians (6,30-33). Neurologic and musculoskeletal pathology resulting from spinal deformity can be treated more effectively with appropriate imaging (31,34,35). The Cobb angle as measured on radiographs is the gold standard for obtaining degrees of curvature, but ultrasound imaging can also effectively be used (6). Prushansky et al. found that this modality gives results that are highly reproducible in young healthy adults with a precision of measurement of 1.2°, 2.6°, 3.8° for the thoracic, lumbar, and cervical regions, respectively (36). A study by Gercek et al. assessing cervical flexion/extension during endotracheal intubation demonstrated precision with their own measurement of 2° (37). Chleboun et al. reported excellent reliability of ultrasound for flexion/extension measurement in the lumbar spine; correlation to MRI was 0.94 (38). Reliability of curvature measurement via ultrasound has also been demonstrated by proxy in other clinical settings. Haque et al. outlined its use in evaluating torticollis in pediatric patients (39). Teng et al. used it to confirm positioning after manual head manipulation by physical therapists (40).

Range of motion
Range of motion testing is employed clinically to assess for spinal pain and possible damage, often without supplementary imaging. However, imaging can shed further diagnostic light, especially if mechanical problems are suspected (37,41). Ultrasound utilized dynamically can investigate the shape of the spine, its motion patterns and relative mobility, and is particularly effective in assessing movement characteristics of the cervical spine (42). As range of motion varies based on body position, Strimpakos et al. (41) showed that inter- and intra-examiner reliability in assessing 3D range of motion is more effective with the subject standing rather than sitting (correlation >0.86 and >0.79, respectively). Further study also demonstrated that range of motion assessment via ultrasound is reliable when compared to plain radiographs as a source of validation (41).
Bones and discs
The bones and intervertebral discs of the spine are affected in a variety of settings including chronic deterioration with aging, traumatic injury, and neurologic spinal pathology (12,32,43,44). Reliable imaging of bone can inform a diagnosis of injury, fracture, or degenerative disease, and may further be employed as a marker for changes in disc height, compression, or extrusion (12,32,43). Marshburn et al. demonstrated how ultrasound used aboard the International Space Station can image cervical vertebrae and intervertebral discs in the C7–T1 region without difficulty or obstruction from vascular structures (9). Ledsome et al. revealed that ultrasound can reliably measure the intervertebral disc distance (45). Finlayson et al. demonstrated that the transverse processes can be clearly identified in the coronal plane (27,45-47). Spinous processes were assessed with greater identification by ultrasound as compared to palpation (48-50). In a study by Ungi et al. (51) articular processes and pedicles were identified and pedicle screw planned placement was tracked by ultrasound with comparable accuracy to CT guided pedicle screw planned tracks. In assessing spinal trauma, Mueller et al. (44) found ultrasound reliable in thoracolumbar burst fracture repositioning when compared to CT. In a prospective study by Vordemvenne et al. (35), ultrasound was also found to be effective in detecting traumatic lesions to the posterior ligamentous complex with 99% sensitivity and 75% specificity (P<0.05), which was comparable to MRI.

Canal structures
Based on the review parameters, evidence was not found specifically assessing the quality of ultrasound imaging of spinal canal pathology in vivo. Multiple studies demonstrating efficacy of ultrasound in this regard used cadaveric models. Although efficacy of diagnosing pathology has not been validated in the articles reviewed, ultrasound was shown to be effective in visualizing attributes of the canal including vertebral level, canal, corpus vertebrae, subarachnoid space, ligamentum flavum, and dura mater (48,51-59).

Ultrasound has been used to accurately assess the size of the canal for determination of possible stenosis or cord compression (44). Edelbauer et al. highlighted that ultrasound can image sensitively into the canal to identify dura mater and detect subdural hematomas (60). Ultrasound has also been used to identify changes to the spinal cord itself, as found by Provoost et al. in a study where they detected a syrinx in the spinal medulla (33).

Use of ultrasound to aid therapeutic intervention
Injections
Numerous clinical procedures involve introduction of instruments, needles, or devices into or around the spine, and ultrasound has been used to enhance physician identification of structures (61). Kim et al. (62) showed that ultrasound is effectively used in cervical epidural steroid injections during these procedures. Ultrasound illustrated high imaging efficacy in transverse and longitudinal views of the C6/C7 area to measure the skin to dura depth, with correlations of 0.9272 and 0.9268 respectively to actual needle depth (52,62-64). Ozer et al. posited that precision of measuring this depth is high enough to derive a statistical model (accounting for BSA, height, weight, and age) for extrapolating values for the L4–L5 interspace (65).

Ultrasound usage in performing nerve blocks was discussed in multiple studies. Bozeaart et al. demonstrated efficacy of nervous structure identification as they visualized spinal exiting nerve roots (66,67). Herring et al. identified branches of spinal roots in visualizing the ventral rami of C1–C4 lateral to the transverse processes, forming the cervical plexus (68). Ilfeld et al. (69) showed similar nerve root visualization with ultrasound in the lumbar spine. Chin et al. (70) showed that ultrasound reduced the technical difficulty and improved clinical efficacy, but cautioned that further validation is still needed (71). In addition to visualizing the nerves themselves, ultrasound use allowed clear identification of the foramen, adjacent structures, interlaminar spaces, epidural/intrathecal spaces, and pedicles (72-75). Facet and para-radicular injections were also aided by administration under ultrasound imaging guidance (47,76-78). Ultrasound user performance was assessed by Finlayson et al., showing reliability for C5–C6 medial branch blocks with a user performance time of 248.8±92.7 seconds for identification of the C7 transverse process and injection of block (46).

Ultrasound-aided injection for management of spinal pathology has been compared to other imaging modalities. Jee et al. found ultrasound to be as effective as fluoroscopy when employed for transforaminal injections (73). Galiano et al. determined that ultrasound was 90% accurate in identification of facet joints when compared against CT imaging (79,80). Obernauer et al. in a similar study assessed speed of injection administration and found that ultrasound was superior to CT guidance for facet joint injections with quicker time to final needle placement (04:46 versus 11:12 and 05:49 versus 14:32 for 1 and 2 levels, respectively) (81).
Lumbar puncture

Lumbar puncture is used to augment clinical suspicion for conditions like meningitis and subarachnoid hemorrhage (82). Duneic et al. (83) showed that lumbar puncture accuracy is improved with ultrasound compared to manual palpation. One study by Peterson et al. contradicts this, asserting that there is no advantage to ultrasound localization for routine lumbar puncture (84). Identification of the intervertebral spaces is typically done through manual palpation, but variability in body habitus can obfuscate structure identification in up to 30% of cases (48,85,86). Ultrasound addresses this challenge by providing an accessible, portable, and affordable visual aid (70,87).

Epidural anesthesia

Epidural anesthesia is commonly used in child delivery and surgical procedures, and requires introduction of a catheter into the spine (67,88). According to the CDC National Vitals and Statistics Report on Epidural and Spinal Anesthesia Use During Labor, approximately 60% of mothers with vaginal deliveries used epidural anesthesia (89). This large quantity of patients may benefit from the reliable visualization offered by ultrasound compared to landmark identification (34,90,91). Epidural catheter placement can be aided by ultrasound, resulting in improved success rate for visualizing the dura and epidural space (49,57,59,74,85,88,92-94). Chin et al. found that ultrasound-aided imaging improves the success rate of spinal anesthesia in adults by 100% (70). Studies have evaluated differing ultrasound techniques, devices, and beams to determine if differences in visual clarity of anatomical features exist, but no significant differences were reported (95-98).

Discussion

Ultrasound has been cited in the literature extensively for utilization as a clinical aid, but not in regard to rigorous analysis of its effectiveness. In the body of research reviewed, nearly all of the structures within the spine have been shown to be clearly visible via ultrasound imaging including musculature, bones and intervertebral discs, nerve roots, the spinal cord, dura mater, facet joints, and foramen (9,12,13). Functional aspects of the spine can also be imaged with ultrasound, with reliability demonstrated in spinal curvature and mobility assessment (38,42). Ultrasound has been used extensively and with accuracy in therapeutic spinal injections (68,81). These studies demonstrate that ultrasound effectively provides visual assessment of the structure and function of the spine and is useful in assisting clinical diagnosis and therapeutic intervention.

Regarding bony work, the preliminary study by Ungi et al. (51) showed comparable accuracy of ultrasound to CT guidance for planning pedicle screw tracks. This is an interesting area for further investigation; if ultrasound can show similar consistent reliability in accurate hardware placement, it may become a very appealing intra-operative modality considering the lack of damaging radiation exposure to both patient and provider. Also intriguing are the studies by Mueller et al. (44) and Vordemvenne et al. (35) assessing ultrasound usage in thoracolumbar burst fracture repositioning and evaluating posterior ligamentous injuries. Despite promising results, it is hard to imagine ultrasound ubiquitously replacing modalities such as CT and MRI in general trauma evaluation. However, employing ultrasound in developing countries or more remote resource stricken settings that simply do not have access to advanced cross-sectional imaging may be a reasonable development. For instance, ultrasound technology has already been used aboard the International Space Station (9), which is arguably one of the most remote and difficult to access areas in terms of resources, with transportation costs of over 10,000 USD per kilogram (99) to the station.

As mentioned above, spinal curvature, mobility, and range of motion have been accurately assessed with ultrasound (38,42). Yet further characterization of these parameters in both normal and pathologic states with ultrasound is needed prior to general adoption in assessing for stable versus unstable injuries after trauma. If this can be accomplished, ultrasound may serve as a valuable and affordable initial survey to identify those patients requiring evacuation to higher level trauma centers.

A limitation to broader ultrasound utilization is the uncertainty in teaching this imaging technique. The literature does not form a strong conclusion whether it can be taught effectively or not. For instance, Margarido et al. showed that 20 supervised trials plus teaching sessions were not enough for the participants to achieve competence in different aspects of ultrasound assessment of the lumbar spine (100). Conversely, Deacon et al. showed after a standardized educational intervention, anesthetic trainees are able to identify a lumbar interlaminar space easily and can measure the depth to the posterior complex after a reasonable number of additional practice scans (101). More robust educational programs (79) and broader availability of ultrasound equipment in training institutions may yield increased fluency in the clinical usage and interpretation of ultrasound acquired images.
Despite the literature presented in the current study, ultrasound is overall cited infrequently for diagnosis of spinal pathology. Less than 10% of the articles reviewed dealt with topics of ultrasound as a spinal diagnostic modality. In modern usage, ultrasound imaging is still most often employed as an aid for procedures involving injection or introduction of needles about the spine. This widespread utilization in procedural guidance demonstrates the ease with which spinal structures are visualized with ultrasound. Once adequate visualization can be established consistently with an imaging modality, diagnostic ability follows. In considering several promising studies delineated above and the portability, affordability, and dynamic imaging characteristics of ultrasound, the authors have the following recommendations: (I) introduce standardized and reproducible educational programs for ultrasound performance and interpretation; (II) continued utilization to aid therapeutic interventions about the spine given the enhanced landmark identification and accuracy; (III) additional studies comparing diagnostic ability of ultrasound against CT and MRI, particularly for (i) vertebral compression fractures and intervertebral disc pathology by assessing vertebral height differences; and (ii) assessing posterior ligamentous complex stability, as this is a common decision point between operative spinal stabilization versus non-operative management (102); (IV) further investigation of ultrasound to guide intra-operative hardware placement, as initial promise has been shown; (V) despite some encouraging results, take caution against premature broad ultrasound implementation for spinal diagnostics due to the lack of a large body of consistent evidence in different settings of spine pathology.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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